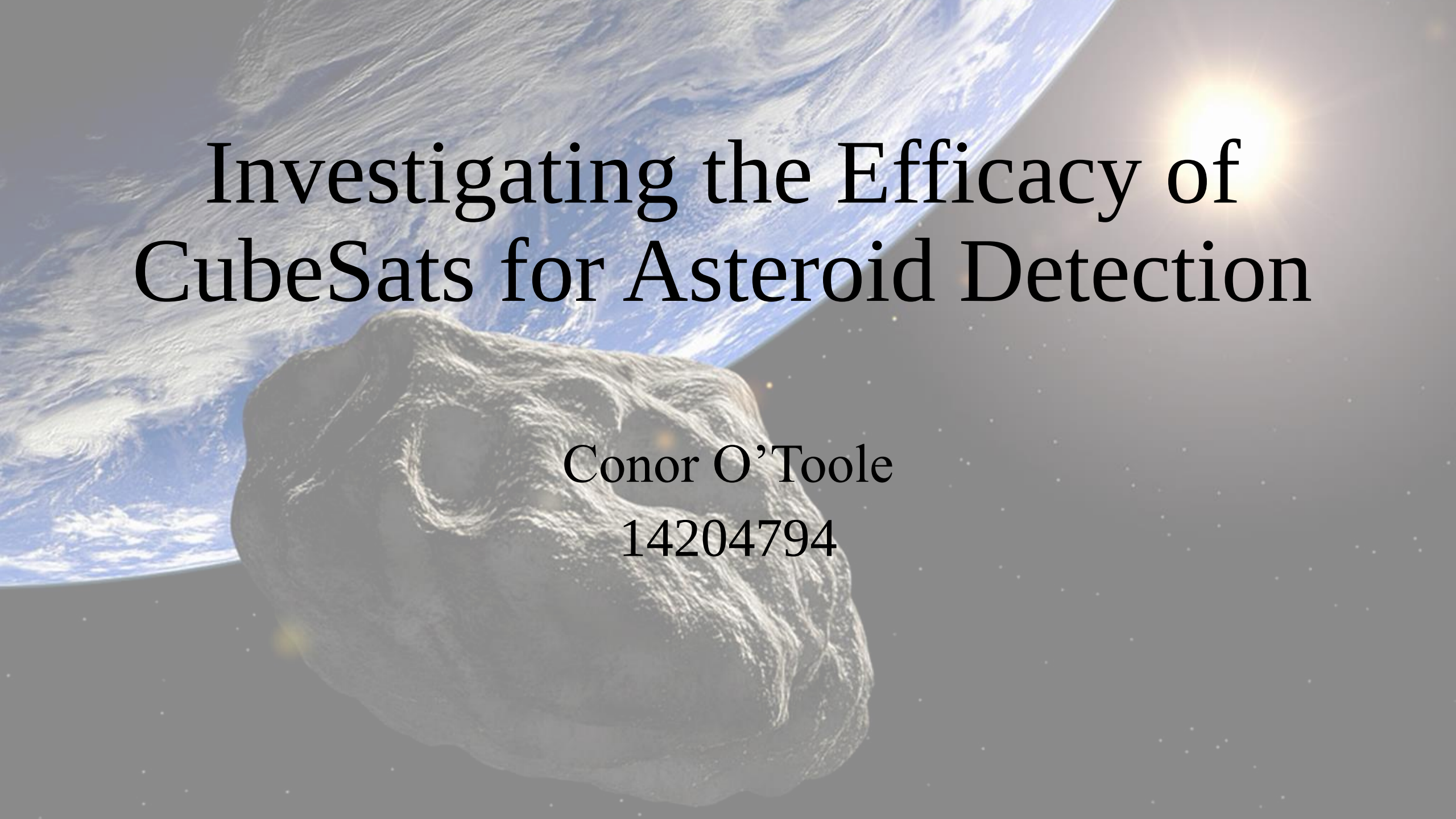


Investigating the Efficacy of CubeSats for Asteroid Detection

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Goals

- To investigate if CubeSats could be used to detect asteroids which could be classified as Near Earth Objects (NEOs), ie. that will come within 1.5AU of Earth at some point.

- A number of factors must be taken into account:
 - Size limit on asteroids?
 - Max distance for detections?
 - One or multiple satellites?
 - Comparison with ground-based surveys

Asteroids

- Left-overs from Solar System formation
- Primarily located in asteroid belts, but many occupy other orbits
- Rate of collision with the planets and moons considered roughly constant
- Ample evidence throughout Solar System

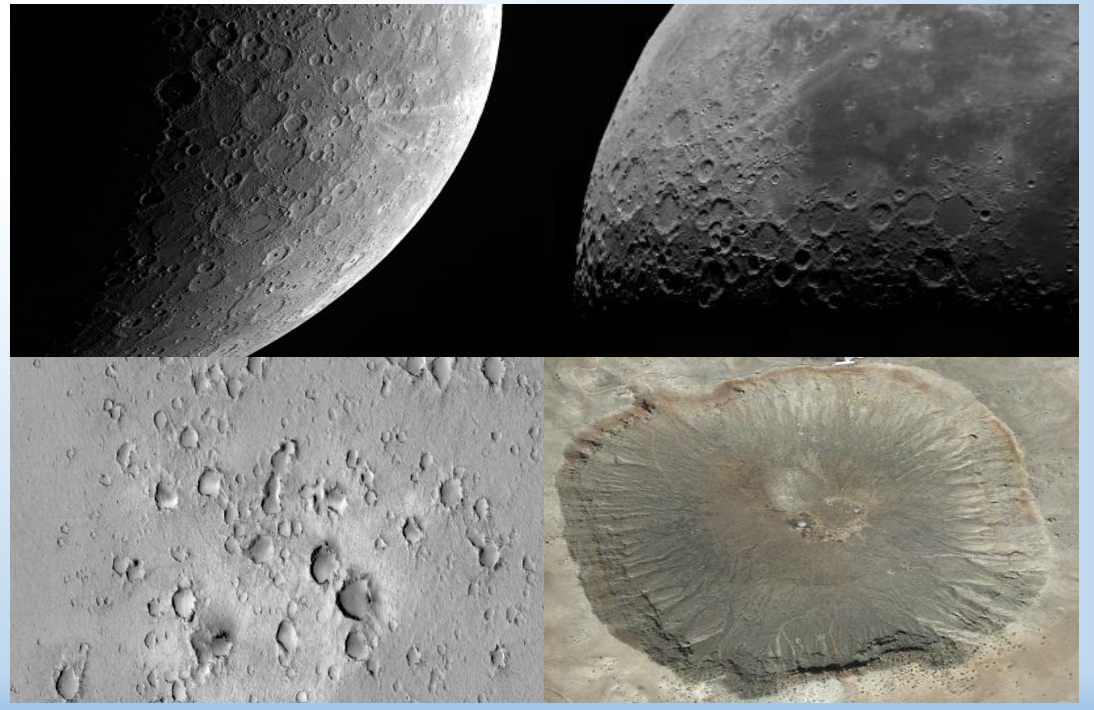


Figure 1: Surfaces of Mercury, Moon, Mars, along with Barringer Crater in Arizona. [1], [2], [3], [4]

NEOs

- ~13,000 NEOs currently catalogued
- 1km scale would cause destruction on a global scale.
- Objects as small as 140m considered a major threat (in light of Chelyabinsk, Tunguska, etc)
- Mitigation techniques in development (eg. Gravity tractor, kinetic impactor, etc)
- Primary concern remains detection

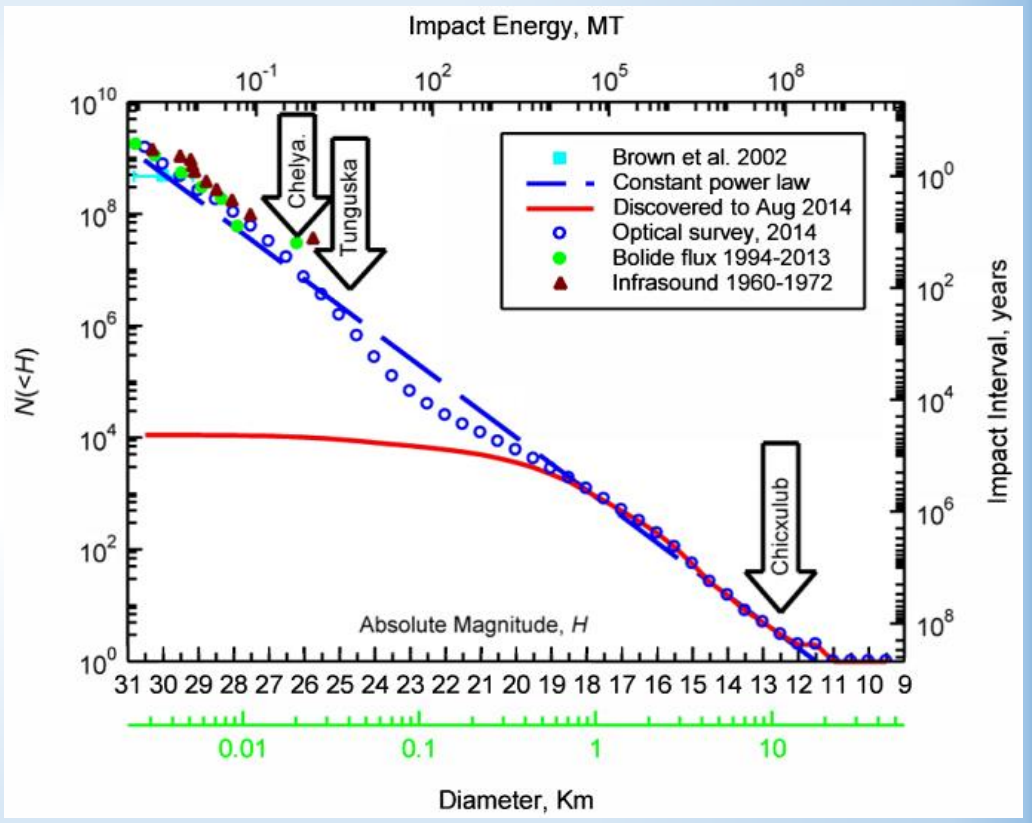


Figure 2: NEOs discovered against predicted values, for a range of sizes. [5]

Asteroid Surveys

- SpaceGuard (1998-2008)
 - Prioritised kilometre scale objects
 - CSS, LINEAR ~ 7,500 discoveries by 2014 ([6], [7])
- ATLAS (late 2015)
 - Early warning system for objects as small as 120m [8]
- MANOS (2013-present)
 - Study physical parameters [9]
- Space-based
 - NEOSSat, launched 2013 [10]
 - Sentinel, planned launch 2018 [11]

LightForce Simulation

- Space debris mitigation proposal [12-14]
- Collision avoidance through ground-based laser stations

- Simulation predicts roughly 90% reduction in number of collisions in the next year
- Currently being extended to 100 years

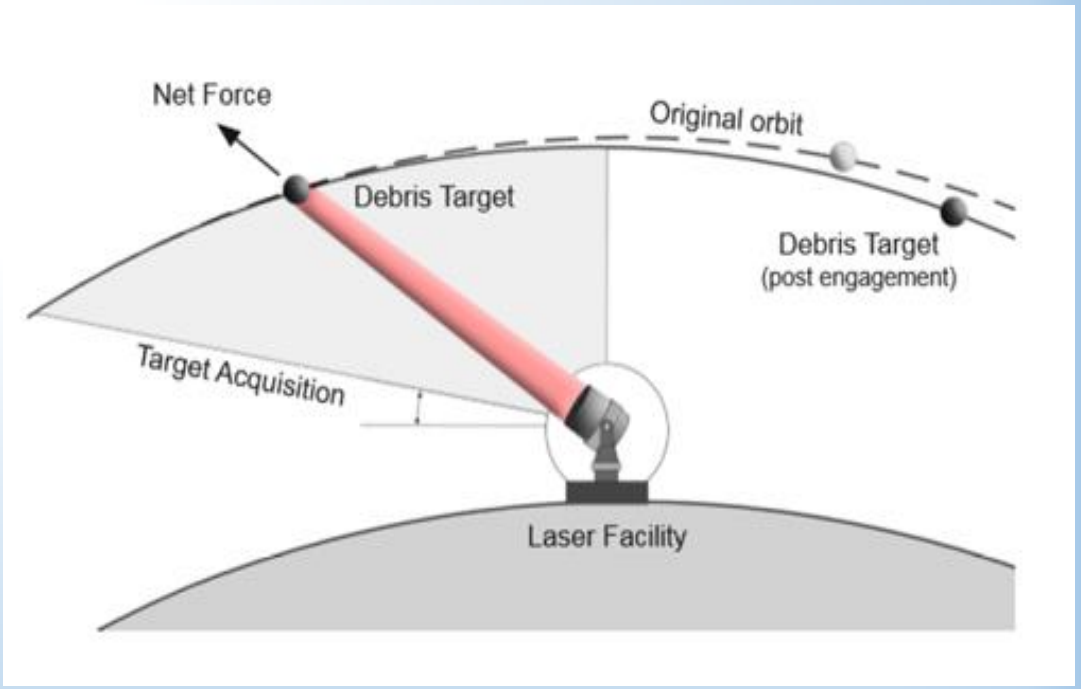


Figure 3: The general technique a LightForce station, either speeding up or slowing down an object to alter it's orbit.

Simulation Approach

LightForce	Our Approach
Earth-centric propagator, propagating debris	Earth-centric propagator, propagating satellites
Debris data obtained from propagator	Asteroid data obtained from SPICE functions [15]
1 year duration	85 year duration
“Illumination” conditions: when to slow-down or speed-up an object	Detection conditions: when is an asteroid successfully detected
Includes uncertainty in debris orbits (to estimate probability of collision)	Does not include the uncertainty in asteroid orbits (due to time constraints)
12,000 debris objects imported	22 asteroids imported
2 steps (with and without LF)	3 steps (propagation, geometric check, optical check)

Asteroid Sample

- 22 NEOs selected from JPL catalogue [16]
- Range of semi-major axes, eccentricities, inclinations and sizes considered (5m - 2.6km diameter range)
- Treated as spheres, with an assumed albedo of 0.154

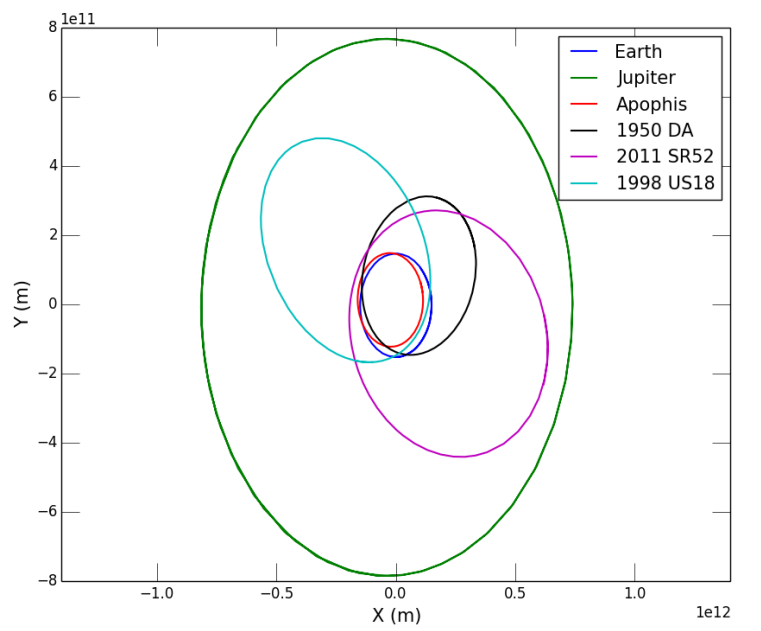
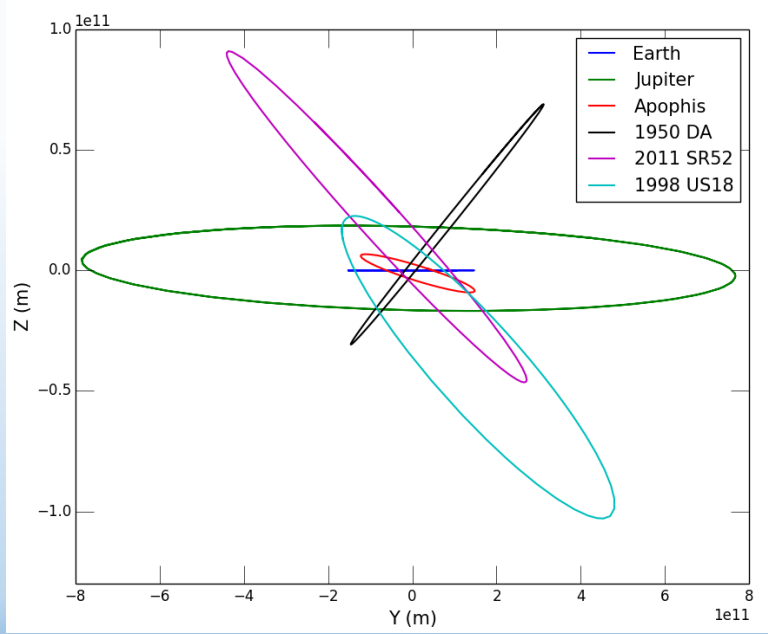


Figure 4: The orbits of a sample of our considered asteroids in the x-y plane (left) and the y-z plane (right), showing the variation in the orbits of our chosen objects.



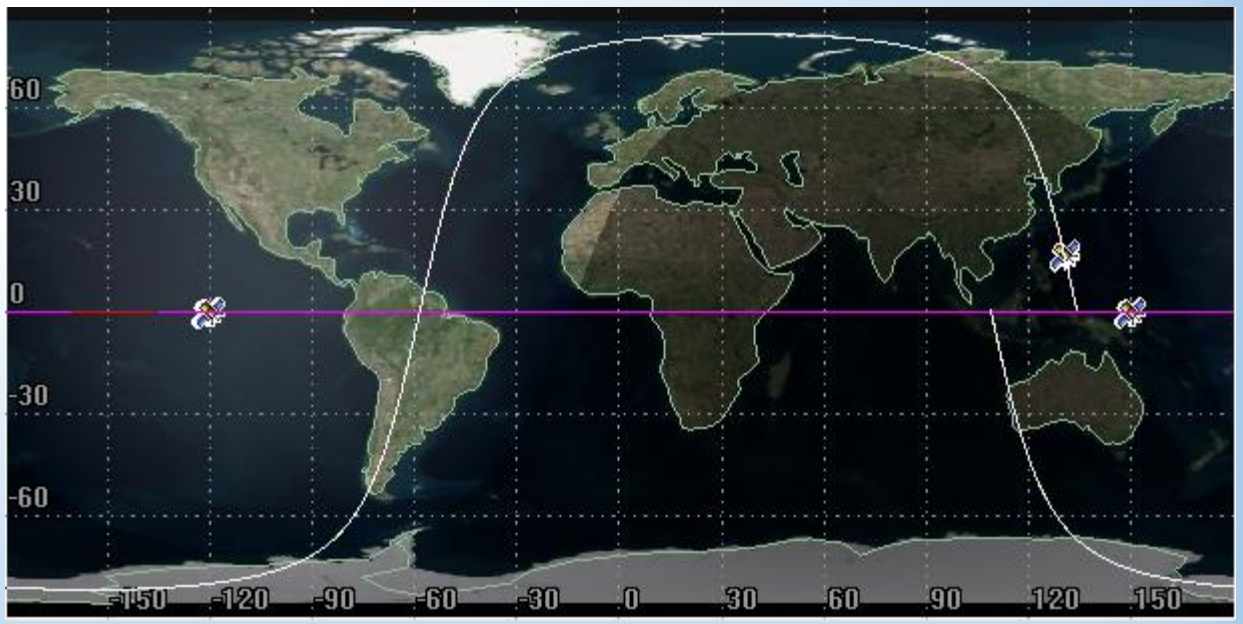
Our Mission

- Each satellite slightly larger than a 6U CubeSat, mass of 6kg
- Same optical system as NEOSSat in each
 - 15cm Maksutov-Cassegrain telescope
 - Limiting magnitude ~ 14.7
 - Exposure time = 120 seconds
 - 2^0 FOV
- To account for limitations of CubeSats, use interferometry and combine images taken by multiple crafts, assuming overlapping FOVs
- Array of 11 satellites, each separated by ~12km, for baseline of 120km
 - Optimal resolution ~ 1 micro-arcsecond
 - Optimal limiting magnitude ~ 22.5

Our Mission

- 3 such arrays
 - 2 equatorial, separated by 90º
 - 1 heliosynchronous, same orbit as NEOSSat
 - Altitude ~ 800 km
 (for simulation purposes only)
- Equatorial arrays point directly away from Earth
- Heliosync. array points 45º from Sun

Figure 5: Orbits of each array in our full satellite network.



Detection Conditions

- 2 types, geometric and optical

- Geometric:
 - Occupies FOV
 - Clear LOS
- Optical
 - Asteroid large enough on sky
 - Asteroid bright enough on sky

General Method

- Propagate CubeSats, saving intermediary steps.
- For each CubeSat, at each time, check if any asteroids are in FOV, with clear LOS.
- For this data, count how many CubeSats have given asteroid in FOV, and calculate baseline separation.
- Calculate angular size and magnitude of asteroid using SPICE functions, and check if these are within the constraints defined by the above step.

Simulation Extension

- Need extended input data to run an 85 year long simulation
 - Ephemeris data, polar corrections and spaceweather data
 - First two obtained from JPL
- Spaceweather data extended using past observations
- Purely statistical method, not physical

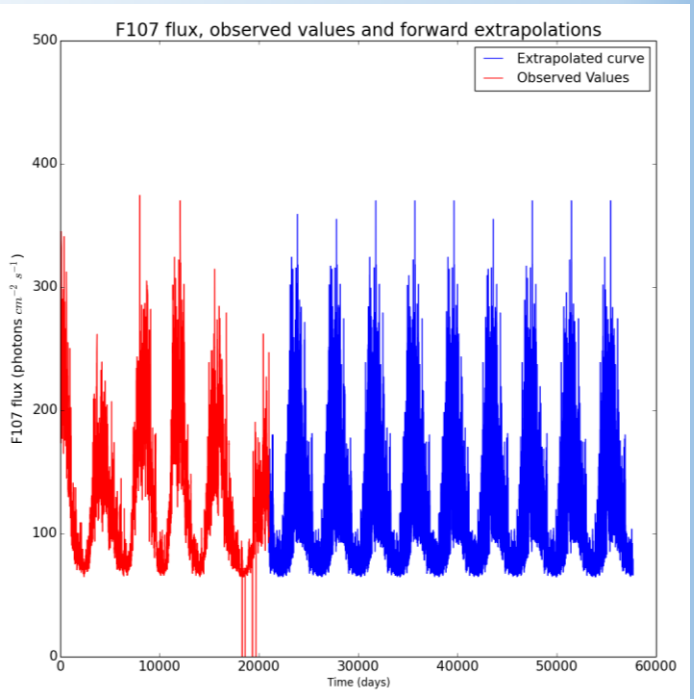


Figure 6: Observed and predicted values of F10.7. The predicted value on any future date was produced by considering intervals around the corresponding point in 4 observed cycles, and drawing a value at random.

Preliminary Results

- Successfully detect 14 of our 22 asteroids
- Smallest detected: diameter of 35m

- Some errors in the code required us to filter the data, removing any data points which exceed the system's capabilities:
 - Time-step: Poor overlap between CubeSats leads to overcounting
 Also to "detections" when separation distance too large
 - Lambert's Law: Oversight regarding large angles results in magnitude calculated as -1

Asteroid	Diameter (m)	Aphelion (AU)	Inclination (^{o})	No. of Detections
410777 (2009 FD)	470	1.736	3.136	2
101955 Bennu (1999 RQ36)	490	1.355	6.035	2
2000 SG344	37	1.044	0.111	21
29075 (1950 DA)	1300	2.561	12.182	412
2001 VB	749	4.547	9.529	10
1979 XB	656	3.735	24.596	13
99942 Apophis (2004 MN4)	370	1.098	3.331	448
2007 FT3	340	1.474	26.822	187
2011 BT59	240	4.863	3.58	6
2001 CA21	681	2.967	4.967	128
2010 WC9	70	1.38	17.989	62
2010 CR5	362	5.533	5.651	27
2011 SR52	2600	4.433	10.654	2
1998 US18	250	4.416	9.666	142
Total	**-**	**-**	**-**	**1462**

Optimal Detections

- Smallest angular size resolved = 246 micro-arceseconds (Apophis)
- Dimmest magnitude detected = 21.6802 (1998 US18)
- Brightest magnitude detected = -5.4422 (Apophis)

- Maximum distance detection registered at = 0.258 AU (2011 SR52)
- Minimum distance detection registered at = 0.0006 AU (Apophis)

Detection Rate

- Spikes due to close approaches of different asteroids.
- Larger catalogue would likely result in far more peaks and fewer dips

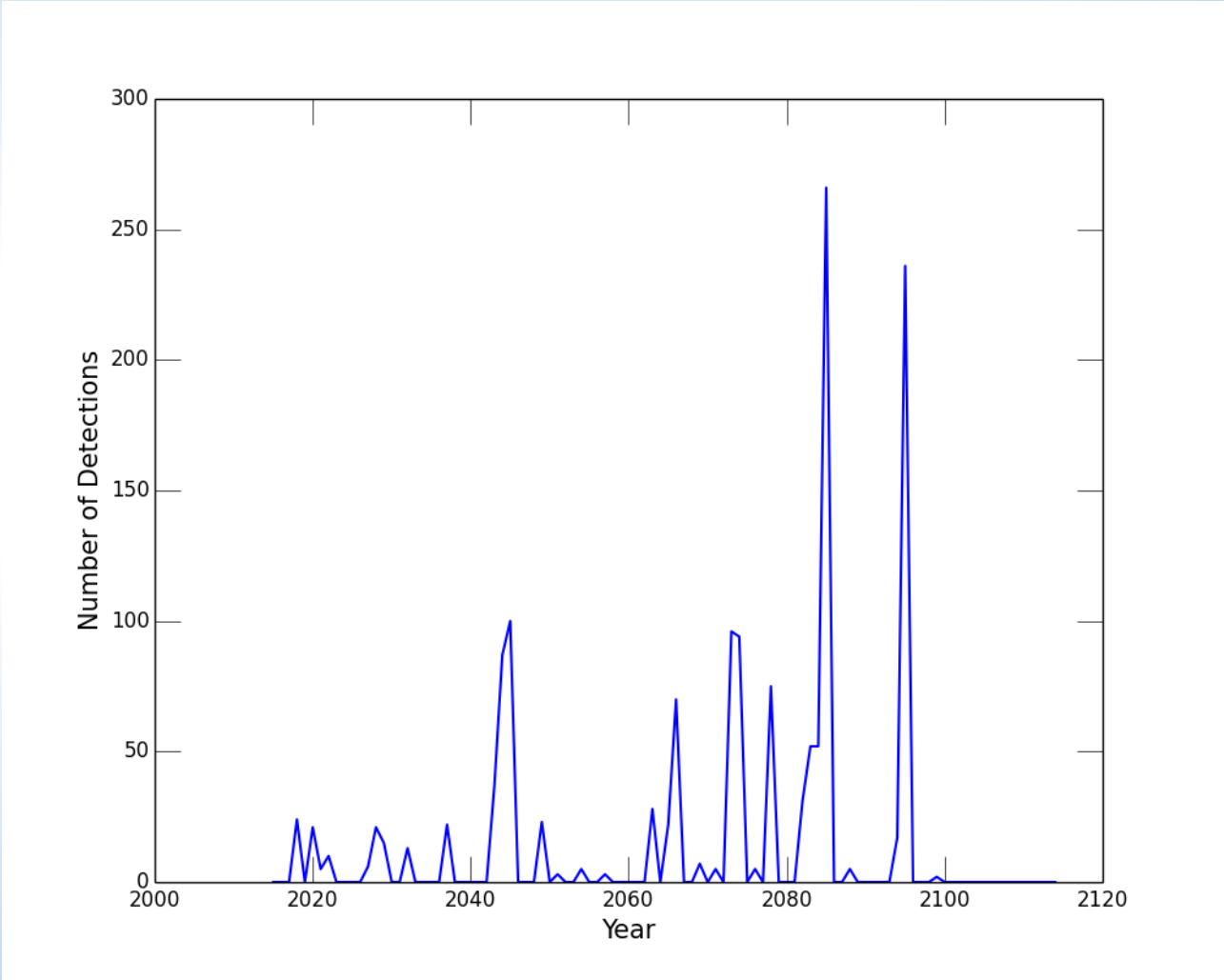


Figure 7: Rate of detection by the entire network over the entire simulation

Satellite Network Performance

No. of CubeSats	No. of detections involving this many satellites
1	0
2	403
3	211
4	7
5	834
6	0
7	2
8	0
9	0
10	1
11	0

Distance Interval	Percentage of Detections with Baseline in this Interval
0-10	28.8066
10-20	8.5048
20-30	5.1440
30-40	5.9671
40-50	6.4472
50-60	5.8985
60-70	7.6818
70-80	6.9273
80-90	9.2593
90-100	6.3786
100-110	2.8807
110-120	3.2236
120-125	2.8807

Asteroid	No. of detections by Arr 1	No. of detections by Arr 2	No. of detections by Arr 3
410777 (2009 FD)	0	2	0
101955 Bennu (1999 RQ36)	2	0	0
2000 SG344	0	0	21
29075 (1950 DA)	45	91	276
2001 VB	3	6	1
1979 XB	8	5	0
99942 Apophis (2004 MN4)	79	216	153
2007 FT3	33	57	97
2011 BT59	0	5	1
2001 CA21	59	62	7
2010 WC9	37	25	0
2010 CR5	18	5	0
2011 SR52	1	1	0
1998 US18	69	73	0
Total	354	548	556

Future Developments

- Number of improvements to be made to current simulation
 - Correct bugs
 - Fix implementation of Lambert’s Law
 - Common time-step vs. interpolation
- Also steps to produce more meaningful results
 - Full asteroid catalogue
 - Improvements to optical systems, inclusion of technical specs

Future Developments

- Several ways to develop the mission simulated
 - Observation campaign
 - Repeat observations
 - Undiscovered asteroids?

- End goal for this simulation
 - Tool for comparing different space missions (particularly SmallSats) in terms of how well they can detect incoming NEOs.

Conclusions

- Foundation laid, a lot still to do.
- Simulation kept as general as possible in most aspects
- Identified several key aspects of data produced

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Thank You

Any Questions?